

# Claims

- [c1] A method of removing phosphorus from phosphorus containing waste, comprising the steps of: (a) contacting the phosphorus containing waste with a non-cellular membrane; and (b) precipitating phosphorus from the waste as struvite.
- [c2] A method according to [c1] wherein the non-cellular membrane is negatively charged and is organized as monolayers, micelles, lamellar bilayers or bilayer vesicles.
- [c3] A method according to [c1] wherein the non-cellular membrane is a "self-assembling monolayer" ("SAM").
- [c4] A method according to [c3] wherein the SAM is formed through a mercapto-derivatized chalcophilic or siderophilic element compound.
- [c5] A method according to [c4] wherein the chalcophilic or siderophilic element is selected from Cu, Ag, Zn, Cd, Ga, In, Tl, Pb, Hg, Bi, Au, Ge, Sn, Ni, Pd and Pt.
- [c6] A method according to [c4] wherein the mercapto-derivatized chalcophilic or siderophilic element compound is copper or gold derivatized with mercapto-undecanoic acid,  $[\text{HS}(\text{CH}_2)_{10}\text{COOH}]$ .
- [c7] A method according to [c6] wherein struvite is further nucleated as crystals on copper or gold derivatized with mercapto-undecanoic acid,  $[\text{HS}(\text{CH}_2)_{10}\text{COOH}]$ .

- [c8] A method according to [c7] wherein the struvite crystallization occurs along the *001* plane, and wherein the struvite structure has planes of Ammonium [1], Magnesium [2] and Phosphate [3] stacked in layers of 2-3-1-2-3-orientation.
- [c9] A method according to [c2] wherein the monomolecular non-cellular membrane has a hydrophobic tail having an acyl chain of 8-24 carbon lengths, and a hydrophilic head group.
- [c10] A method according to [c2] wherein the acyl chain is saturated, unsaturated or esterified.
- [c11] A method according to [c9] wherein the head group is selected from the group consisting of sulfonic acid, carboxylate, sulfate, sulfonate, perfluorosulfonate, phosphate, phosphonate and alcohol.
- [c12] A method according to [c2] wherein the carboxylic acid is selected from the group consisting stearic acid, stearyl sulfate, stearyl sulfonate, stearyl phosphate, stearyl phosphonate and stearyl alcohol.
- [c13] A method according to [c1] wherein the membrane is a polymeric membrane.
- [c14] A method according to [c13] wherein the polymeric membrane is selected from the group consisting of negatively charged sulfonic acid, carboxylate, sulfate, sulfonate, perfluorosulfonate,

phosphate, phosphonate and alcohol, and combinations thereof, embedded in a nylon or acrylic membrane.

- [c15] A method according to [c1] wherein the phosphorus containing waste has a pH between 7 and 14.
- [c16] A method according to [c1] wherein the phosphorus containing waste has a pH between 8 and 10.
- [c17] A method according to [c1] further comprising the step of adding ferric chloride to the phosphorus containing waste and precipitating phosphorus.
- [c18] A method according to [c1] wherein the phosphorus containing waste is selected from the group consisting of biosolids, bioliquids, water bodies, solutions, colloids and precipitates.
- [c19] An apparatus for removing phosphorus from phosphorus containing waste, comprising: a first chamber for containing phosphorus containing waste; a second chamber for containing suitable ionic salts and solutions; a membrane separating the first and second chambers, wherein the membrane is held and sealed between the first and second chambers and is suitable for cation exchange.
- [c20] An apparatus according to [c19] wherein suitable cation exchange membrane is a polymeric acrylic membrane containing functional groups selected from the group consisting of sulfonic

acid, carboxylate, sulfate, sulfonate, perfluorosulfonate, phosphate, phosphonate and alcohol.

- [c21] An apparatus according to [c19] wherein suitable ionic salts and solutions are selected from the group consisting of  $\text{MgCl}_2$ ,  $\text{MgO}$ ,  $\text{Mg}(\text{OH})_2$ ,  $\text{Mg}(\text{O}_2\text{CCH}_3)_2$  and  $\text{MgSO}_4$ .
- [c22] An apparatus according to [c19] wherein no fresh phosphorus containing waste and ionic salts and solutions are added.
- [c23] An apparatus according to [c19] wherein fresh phosphorus containing waste and fresh ionic salts are added, optionally as countercurrents, whereby direction of addition of fresh phosphorus containing waste is opposite to the direction of addition of fresh ionic salt and solutions.
- [c24] An apparatus according to [c19] wherein fresh phosphorus containing waste and spent ionic salts and solutions are added at one end and substantially struvite stripped phosphorus containing waste and fresh ionic salts and solutions are added at an opposing end, thereby forming a multistage reactor.
- [c25] A method of removing phosphorus from phosphorus containing sewage including filtrate and biosolids comprising the steps of: (a) contacting the sewage with a first polymeric membrane reactor and removing phosphorus as primary struvite; (b) adding Mg to make the sewage supersaturated with struvite; and (c) contacting the sewage with a second monomolecular membrane

and removing phosphorus as secondary struvite.

- [c26] A method according to [c25] wherein the first polymeric membrane is selected from the group consisting of a negatively charged nylon polymeric membrane and negatively charged acrylic polymeric membrane.
- [c27] A method according to [c25] wherein the second monomolecular membrane is selected from the group consisting of stearic acid membrane, stearyl sulfate membrane, stearyl sulfonate membrane, stearyl phosphate membrane, stearyl phosphonate membrane and stearyl alcohol membrane.
- [c28] A method according to [c25] wherein the phosphorus containing sewage has a pH between 8-10.
- [c29] A method according to [c25] further comprising the step of contacting sewage biosolid with ferric chloride and precipitating phosphorus.
- [c30] A method according to [c25] wherein the phosphorus containing sewage has passed through at least a dewatering unit, GBT, GBT Filtrate Well, Centrifuge, or Centrifuge Well prior to removal of phosphorus by said method.
- [c31] A method of removing phosphorus, potassium, ammonium, magnesium, selenium arsenic from waste containing phosphorus, potassium, ammonium, magnesium, selenium or

arsenic, comprising the steps of: (a) contacting the waste with a non-cellular membrane; and (b) precipitating phosphorus, potassium, ammonium, magnesium, selenium or arsenic from the waste as struvite or analog thereof.

[c32] A method according to [c31] wherein the non-cellular membrane is negatively charged and is organized as monolayers, micelles, lamellar bilayers or bilayer vesicles.

[c33] A method according to [c31] wherein the non-cellular membrane is a "self-assembling monolayer" ("SAM").

[c34] A method according to [c33] wherein the SAM is formed through a mercapto-derivatized chalcophilic or siderophilic element compound.

[c35] A method according to [c34] wherein the chalcophilic or siderophilic element is selected from Cu, Ag, Zn, Cd, Ga, In, Tl, Pb, Hg, Bi, Au, Ge, Sn, Ni, Pd and Pt.

[c36] A method according to [c31] wherein struvite analog is  $\text{MgKPO}_4 \cdot 6\text{H}_2\text{O}$ ,  $\text{MgNH}_4\text{AsO}_4 \cdot 6\text{H}_2\text{O}$ ,  $\text{MgNH}_4\text{SeO}_4 \cdot 6\text{H}_2\text{O}$ ,  $\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$ , or  $\text{K}_2\text{Mg}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ .